HOT AIR?

Hyundai says that "building a comprehensive hydrogen ecosystem… will lead to a paradigm shift that removes automobile emissions from the environmental equation". But are hydrogen fuel cell-powered heavy vehicles a realistic proposition, asks Toby Clark

Hydrogen fuel cells have promised to be the future of renewable energy-powered transport for decades. Progress has not always been smooth, thanks to initial expense, range issues, a lack of fuelling infrastructure – and perhaps a prejudice that hydrogen is dangerous. The fuel cell-powered electric vehicles (FCEVs) that have appeared have typically been heavily subsidised public transport or research projects (for example, see also *www.is.gd/hecosa*).

But there has been significant progress toward using fuel cells on an entirely commercial basis. The demand for 'zero-emissions' vehicles has coincided with ever-cheaper solar and wind energy and widespread adoption of electric drivetrains. And fuel cells promise rapid refuelling, rather than the lengthy charging process for battery-powered vehicles.

This is a pretty dynamic sector: Hyundai is delivering mass-produced heavy trucks with fuel cell power; Nikola is about to start producing fuel cell-powered trucks at the IVECO plant in Ulm, and Daimler Truck and Volvo last month agreed a fuel cell joint venture; the former partner has plans to offer vehicles (pictured) in five years' time.

HOW THEY WORK

Hydrogen (H_2) is in some ways the holy grail of fuels: when you extract energy from it, in theory the only by-product is water (H_2O), unlike hydrocarbon fuels which inevitably produce CO_2. There are plenty of examples of hydrogen-powered internal combustion engines (cars from BMW and Mazda, and a few forklift trucks and vans – and see pp14-15), but high combustion temperatures mean that such engines tend to produce undesirable levels of NOx.

Hydrogen fuel cells are the alternative: these use an electrochemical reaction to combine hydrogen with oxygen to produce water and an electric current (see Ballard diagram, p12). This was demonstrated as long ago as 1838, and fuel cells have long been used in the space programme, but it was not until the development of PEM (proton exchange membrane) fuel cells that they became commercially viable.

In principle, the fuel cell consists of an anode on one side, a cathode on the other, and an electrolyte that allows ions (charged molecules) to move between the two. Hydrogen is introduced at the anode, where a catalyst strips the H_2 molecules of electrons, creating positively-charged hydrogen ions; these travel to the cathode via the electrolyte, passing through a membrane which

VAN HOOL FUEL CELL BUSES

The French city of Pau has ruled that all new public transit vehicles should produce zero emissions, and chose FCEVs for its new bus fleet. Operator Fébus calculated that its routes could be served by eight FCEVs with a single refuelling depot, rather than 14 battery-electric buses and two charging stations.

The Van Hool ExquiCity tram-buses use Ballard fuel cells and have a range of 450km. The operator cites other advantages over battery-electric buses: the flexibility to take on special routes; easily scalable fuelling infrastructure, and better performance in cold weather.

allows only these ions to go through. The electrons go to the cathode via an external electrical circuit, generating DC current. At the cathode, oxygen (or air) is introduced, where it reacts with the hydrogen ions and electrons to produce water and waste heat. This heat means that a fuel cell is generally 40-60% efficient – better than almost all internal combustion engines – and in practice there can be other emissions such as a small amount of nitrogen dioxide. Each fuel cell produces a low voltage, so they are stacked in series.

The catalyst within the fuel cell typically contains platinum, but recent developments have refined its microscopic structure to reduce the amount needed, and alternatives such as cobalt-nitrogen-carbon catalysts are looking promising.

The lifetime of the fuel cell itself is an issue, with some manufacturers reporting a service life of only a few thousand hours – unlikely to be enough for a heavy truck or bus. However, Nikola founder Trevor Milton compares his heavy trucks to battery-electric alternatives: "You can run hydrogen 24/7 and it only takes 15 minutes to top off and continue on the road… [and] a fuel cell has minimal rebuild costs after 20,000 hours ($5,000-$10,000 compared to $240,000 BEV battery replacements)". The fuel cell's life is shortened by transient loads; this can be improved with a 'hybrid' approach – using a battery or ultracapacitor to supplement the fuel cell at times of high power demand.

STORAGE ISSUES

Hydrogen has an exceptionally high specific energy (energy per unit mass) of around 120MJ/kg, versus around 46MJ/kg for diesel. This compares with a figure of just 1MJ/kg for the best lithium-ion batteries. However, its extremely low density means that the energy per unit volume is much lower: compressed to 700 bar, it has an energy density of just 5MJ/lit compared with 9MJ/lit for CNG (at 250 bar) or 38MJ/lit for diesel. Even liquid hydrogen has an energy density of just 8MJ/lit, compared with 22MJ/lit for LNG. However, it still compares well with Li-ion batteries, which struggle to better 3MJ/lit.

Hydrogen is usually stored as a gas, under high pressure. Trucks and

GREEN HYDROGEN

Fuel is the key to making hydrogen-powered vehicles a realistic proposition; while hydrogen is the most common element, it generally needs to be derived from other materials. Fortunately, this is straightforward: just apply an electric current to a couple of electrodes in water, and hydrogen will be produced at the anode – right? Not quite.

In fact, most hydrogen for industrial purposes is produced from natural gas (CH_4) using a technique called steam methane reforming (SMR) which produces a great deal of CO_2 as a byproduct. The vast majority of hydrogen is used for producing ammonia-based fertilisers and for 'hydrocracking' heavy fossil fuels to produce lighter, more usable fractions.

'Greener' techniques for making hydrogen include methane pyrolysis, which produces only solid carbon (with no greenhouse gas potential), and various biological reactions using algae to split water. But hydrogen may not even need to be manufactured: recently 'native' hydrogen has been extracted from wells in Mali, and is being investigated elsewhere.

In any case, 'green hydrogen' usually means electrolysing water with electricity from renewable sources. This can make the most of variable sources such as wind and solar power: when electricity demand is low it can be diverted to hydrogen production, and when generating capacity is low, fuel cell generators can pick up the slack. (This is the plan to power Translink's three new H_2 buses in Belfast – see *www.is.gd/efetew*.)

'Green' hydrogen is currently expensive: two to six times as costly as SMR. But with renewable energy becoming ever-cheaper, it becomes more attractive every day. Ballard and Deloitte published a report last year which claimed that the total cost of ownership of a fuel cell-powered bus will fall by more than 50% within five to seven years (*www.is.gd/ucaram*), while Bank of America predicted that green hydrogen could make up 24% of global energy needs by 2050.

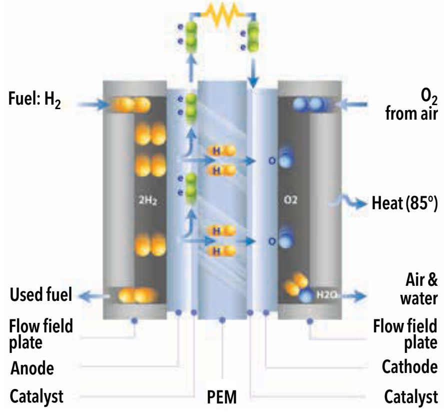
As part of its 'green industrial revolution' plan, the UK government has pledged to develop 5GW of low-carbon hydrogen production capacity by 2030.

> ***"Wear and tear can be caused by thermal expansion, and if the thermal management system isn't working as it should then that could cause failure of the electric motor"***
> Gavin Takel

buses typically have 350-bar tanks, whereas cars (limited by space rather than weight) tend to use 700-bar tanks. The tanks are typically made of carbon fibre-reinforced polymer (CFRP) around a moulded liner, with a metal end boss. These 'Class IV pressure vessels' have undergone stringent impact and wear testing, but they are much lighter than equivalent steel tanks: manufacturer Nproxx reckons that they save around 450kg in a bus or truck, and claims a 30-year lifespan.

Hydrogen is sometimes stored as a liquid (LH2), but this requires extreme cryogenic temperatures; at atmospheric pressure, hydrogen boils at -253°C, whereas methane (LNG) boils at -162°C. It may also be stored as a solid in the form of a metallic hydride, to be released as a gas when needed. This promises safe, energy-dense and long-term storage, but issues with thermal management and expense mean that it is not ready for production vehicles yet.

How a fuel cell works (diagram: Ballard)



SERVICE & MAINTENANCE

Workshops for FCEVs need some adaptation, but anybody with a CNG-powered fleet would be familiar with most of the measures. The depot should have a defuelling system which purges the hydrogen using an inert gas such as nitrogen, and allows the fuel to be stored or vented. Hydrogen is much lighter than air, so it will end up at the highest point in the workshop; these areas need proper ventilation.

Fuel cell manufacturer Ballard also recommends a two-stage hydrogen detection system with "Level 1 indicators (for example, flashing beacons) that are activated at 20% of the lower explosion limit (LEL), and a Level 2 (with full audible alarm and flashing beacons) at 40% LEL".

Of course heat, electrical sparks and other ignition sources should also be kept away from hydrogen. And the electrical components of the vehicle need special care and appropriate safety gear – although, unlike traction batteries, fuel cells do not store significant amounts of electricity.

Apart from regular inspection of storage tanks, there are few issues with maintenance. Gavin Takel, technical sales manager at components supplier Imperial Engineering, says that when fleets move to electric or hybrid power "there is no change in the routine when it comes to inspection of brakes and suspension". In fact, it has "a very positive effect on the brake maintenance: there's less wear and tear on discs and pads, and less downtime". He points out that this has a knock-on effect on non-exhaust particulate emissions (NEEs): a DEFRA report from 2019 suggested that at least 47% of atmospheric copper emissions come from brake wear.

Electric drivelines themselves require very little maintenance, and wear is likely to be slow: Tesla claims its Model 3's driveline is "designed and validated for over 1 million miles". But Takel suggests some caution: "Wear and tear can be caused by thermal expansion, and if the thermal management system isn't working as it should then that could cause failure of the electric motor. But operators I've dealt with have had minimal issues with the drive motor; any failures haven't been to do with wear and tear but with electronics." TE

HYUNDAI XCIENT FUEL CELL TRUCK

Hyundai handed over its first XCIENT Fuel Cell trucks to customers in Switzerland last September, aiming to deliver 1,600 units by 2025. An early customer is the haulier Weiss Brothers (see *www.is.gd/rirebo*).

The 19t GVW 4x2 rigid XCIENT is powered by dual 95kW fuel cell stacks. Seven 350-bar hydrogen tanks store around 32kg, for a range of around 400km even when operating as a 34-tonne drawbar reefer combination. Refuelling takes approximately 8-20 minutes.

Hyundai Hydrogen Mobility (HHM), a joint venture with Swiss company H2 Energy, leases the trucks to commercial operators on a pay-per-use basis. Switzerland offers zero road tax for 'zero-emission' trucks – said to "nearly equalise the hauling costs per kilometre of the fuel cell truck compared to a regular diesel truck" – and is a leading producer of hydroelectric power, which can be used to provide 'green' hydrogen.

Hyundai plans to expand the project to other European countries, and to open up the fuelling network to passenger cars too – it aims to sell 110,000 FCEVs (mostly cars) each year by 2025. The firm is also developing a tractive unit with a 1,000-km range for global markets including Europe.